BOONTON

BOONTON ELECTRONICS CORPORATION

POWER SENSOR MANUAL

MP MASTER

MA26616

POWER SENSOR MANUAL

BOONTON

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SAFETY SUMMARY

The following general safety precautions must be observed during all phases of operation and maintenance of this instrument. Failure to comply with these precautions or with specific warnings elsewhere in this manual violates safety standards of design, manufacture, and intended use of the instruments. Boonton Electronics Corporation assumes no liability for the customer's failure to comply with these requirements.

THE INSTRUMENT MUST BE GROUNDED.

To minimize shock hazard the instrument chassis and cabinet must be connected to an electrical ground. The instrument is equipped with a three conductor, three prong AC power cable. The power cable must either be plugged into an approved three-contact electrical outlet or used with a three-contact to a two-contact adapter with the (green) grounding wire firmly connected to an electrical ground at the power outlet.

DO NOT OPERATE THE INSTRUMENT IN AN EXPLOSIVE ATMOSPHERE.

Do not operate the instrument in the presence of flammable gases or fumes.

KEEP AWAY FROM LIVE CIRCUITS.

Operating personnel must not remove instrument covers. Component replacement and internal adjustments must be made by qualified maintenance personnel. Do not replace components with the power cable connected. Under certain conditions dangerous voltages may exist even though the power cable was removed; therefore, always disconnect power and discharge circuits before touching them.

DO NOT SERVICE OR ADJUST ALONE.

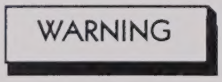
Do not attempt internal service or adjustment unless another person, capable of rendering first aid and resuscitation, is present.

DO NOT SUBSTITUTE PARTS OR MODIFY INSTRUMENT.

Do not install substitute parts of perform any unauthorized modification of the instrument. Return the instrument to Boonton Electronics for repair to ensure that the safety features are maintained.

This safety requirement symbol has been adopted by the International Electrotechnical Commission, Document 66 (Central Office) 3, Paragraph 5.3, which directs that an instrument be so labeled if, for the correct use of the instrument, it is necessary to refer to the instruction manual. In this case it is recommended that reference be made to the instruction manual when connecting the instrument to the proper power source. Verify that the correct fuse is installed for the power available, and that the switch on the rear panel is set to the applicable operating voltage.

The CAUTION sign denotes a hazard. It calls attention to an operation procedure, practice, or the like, which, if not correctly performed or adhered to, could result in damage to or destruction of part or all of the equipment. Do not proceed beyond a CAUTION sign until the indicated conditions are fully understood and met.



The WARNING sign denotes a hazard. It calls attention to an operation procedure., practice, or the like, which, if not correctly performed or adhered to, could result in injury or loss of life. Do not proceed beyond a warning sign until the indicated conditions are fully understood and met.

This SAFETY REQUIREMENT symbol has been adopted by the International Electrotechnical Commission, document 66 (Central Office)3, Paragraph 5.3 which indicates hazardous voltage may be present in the vicinity of the marking.

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Introduction

1-1 Overview

The overall performance of a power meter is dependent upon the sensor employed. Boonton Electronics Corporation (BEC) has addressed this by providing quality power sensors to meet virtually all applications. BEC offers a family of sensors with frequency ranges spanning 10 kHz to 100 GHz and sensitivity from 0.1 nW (-70 dBm) to 25 W (+44 dBm). A choice of Diode or Thermocouple Sensors with 50 or 75 ohms impedances in Coaxial or Waveguide styles are available.

1-2 Sensor Trade-offs

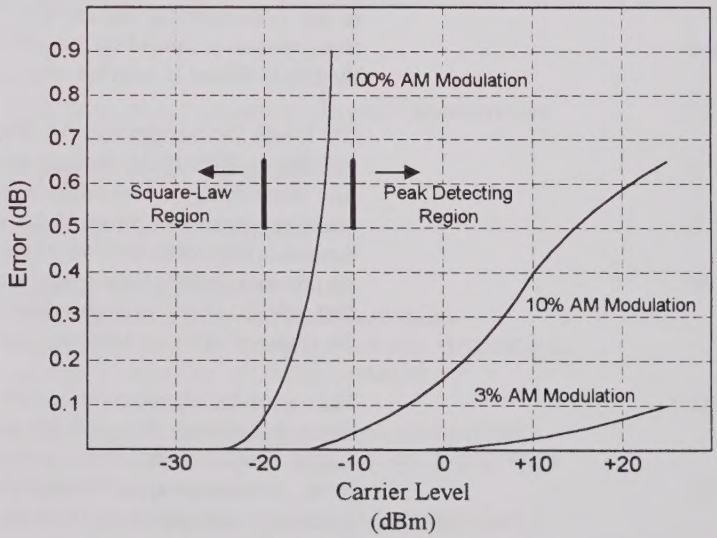
Both the Thermocouple and Diode Sensors offer unique advantages and limitations. Thermocouple Sensors measure true RMS power over a dynamic range from 1.0 μW (-30 dBm) to 100 mW (+20 dBm), and therefore, are less sensitive to non-sinusoidal signals and those signals with high harmonic content. The Thermocouple Sensors also provide advantages when making pulsed RF measurements with extremely high crest factors. While the headroom (the difference between the rated maximum input power and burnout level) for CW (continuous wave) measurements is only a few dB (decibels), Thermocouple Sensors are very rugged in terms of short duration overload. For example, a sensor that operates up to 100 mW average power (CW) can handle pulses up to 15 watts for approximately two microseconds. One of the major limitations to the Thermocouple Sensor is on the low-end sensitivity. Low-end sensitivity of these sensors is limited by the efficiency of the thermal conversion. For this reason, the Diode Sensor is used for requirements below 10 μW (-20 dBm).

CW Diode Sensors provide the best available sensitivity, typically down to 0.1 nW (-70 dBm). BEC Diode Sensors are constructed using balanced diode detectors. The dual diode configuration offers increased sensitivity as well as harmonic suppression when compared to a single diode sensor. The only significant drawback to Diode Sensors is that above the level of approximately 10 μW (-20 dBm), the diodes begin to deviate substantially from square-law detection. In this region of 10 μW (-20 dBm) to 100 mW (20 dBm), peak detection is predominant and the measurement error due to the presence of signal harmonics is increased.

The square-law response can be seen in Figure 1-1, where a 100% amplitude modulated signal is shown to have virtually no effect on the measured power at low levels. Of course, frequency modulated and phase modulated signals can be measured at any level, since the envelope of these modulated signals is flat. Frequency shift keyed and quadrature modulated signals also have flat envelopes and can be measured at any power level.

This non-square-law region may be "shaped" with meter corrections, but only for one defined waveform, such as a CW signal. By incorporating "shaping", also referred to as "Linearity Calibration", BEC offers a dynamic range from 0.1 nW (-70 dBm) to 100 mW (+20 dB) with a single sensor module. For CW measurements, the entire 90 dB range can be used, however, when dealing with non-sinusoidal and high-harmonic content signals, the Diode Sensor should be operated only within its square-law region (10 μW and below).

Although thermal sensors provide a true indication of RMS power for modulated (non-CW) signals, they are of limited use for characterizing the short-term or instantaneous RF power due to their rather slow response speed. For accurate power measurements of short pulses or digitally modulated carriers, BEC has developed a line of wideband diode sensors called Peak Power Sensors. These sensors are specially designed for applications where the instantaneous power of an RF signal must be measured with high accuracy. They are for use with the Boonton Model 4400 peak Power Meter and the Model 4500 Digital Sampling Power Analyzer. Because the bandwidth of Peak Power Sensors is higher than most modulated signals (30 MHz or more for some sensor models), they accurately respond to the instantaneous power envelope of the RF signal, and the output of the sensor may be fully linearized for any type of signal, whether CW or modulated. BEC Peak Power Sensors contain built-in nonvolatile memory that stores sensor information and frequency correction factors. The linearity correction factors are automatically generated by the instrument's built-in programmable calibrator. With the high sensor bandwidth, and frequency and linearity correction applied continuously by the instrument, it is possible to make many types of measurements on an RF signal; average (CW) power, peak power, dynamic range, pulse timing, waveform viewing, and calculation of statistical power distribution functions.



Note: The error shown is the error above and beyond the normal power increase that results from modulation.

Figure 1-1. Error Due to AM Modulation (Diode Sensor)

1-3 Calibration and Traceability

BEC employs both a linearity calibration as well as a frequency response calibration. This maximizes the performance of Diode Sensors and corrects the non-linearity on all ranges.

Linearity calibration can be used to extend the operating range of a Diode Sensor. It can also be used to correct non-linearity throughout a sensor's dynamic range, either Thermocouple or Diode. A unique traceability benefit offered is the use of the 30 MHz working standard. This is used to perform the linearization. This standard is directly traceable to the 30 MHz piston attenuator maintained at the National Institute of Standards Technology (NIST). Refer to Figure 1-2. Linearity Traceability.

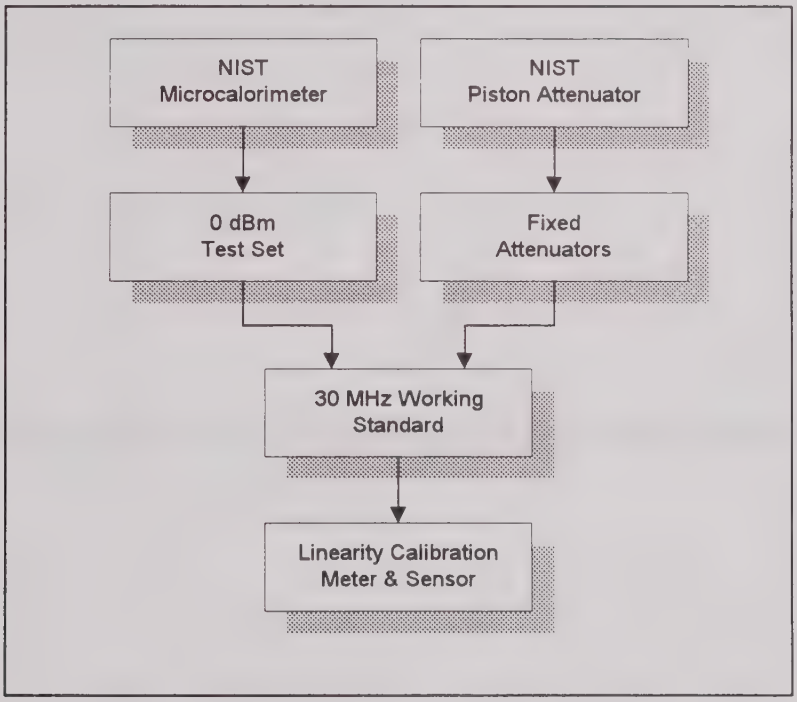


Figure 1-2. Linearity Traceability

Power sensors have response variations (with respect to the reference frequency) at high frequencies. Calibration factors ranging from ± 3 dB are entered into the instrument memories at the desired frequencies. Generally, calibration factors are within ±0.5 dB. These calibration factors must be traceable to the National Institute of Standards Technology (NIST) to be meaningful. This is accomplished by sending a standard power sensor (Thermocouple type) to NIST or a certified calibration house and comparing this standard sensor against each production sensor. The predominant error term is the uncertainty of the reference sensor, which is typically 2% to 6%, depending on the frequency. Refer to Figure 1-3. Calibration Factor Traceability.

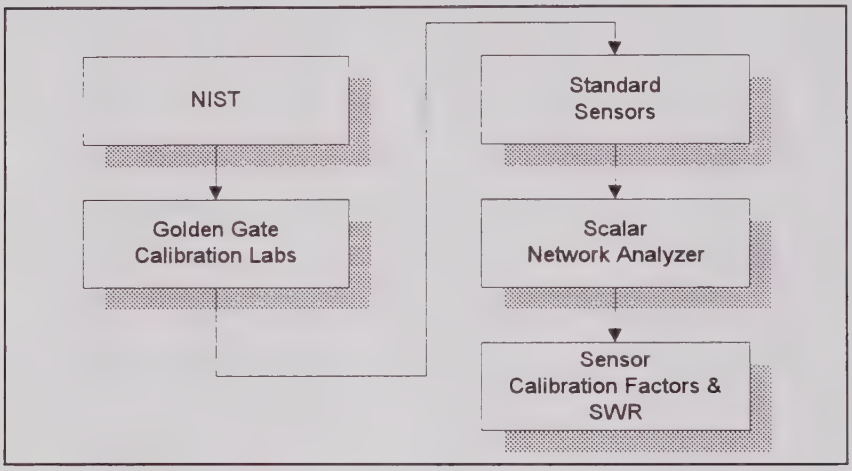


Figure 1-3. Calibration Factor Traceability

Power Sensor Characteristics

The power sensor has three primary functions. First the sensor converts the incident RF or microwave power to an equivalent voltage that can be processed by the power meter. The sensor must also present to the incident power an impedance which is closely matched to the transmission system. Finally, the sensor must introduce the smallest drift and noise possible so as not to disturb the measurement.

Table 2-1 gives the Diode and Thermocouple Sensor Characteristics while Tables 2-2 and 2-3 list these data for the Peak Power and Waveguide Sensors respectively.

Table 2-1. Dual Diode and Thermocouple Sensor Characteristics

Model (Impedance) (RF Connector)	Freq. Range	Dynamic Range 4200A 4220A 4300 Note 7	Overload Rating Peak Power CW Power	Maximum SWR Frequency	Maximum SWR SWR	Drift and Noise Lowest Range Drift (typical) 1 HR (Note 4)	Drift and Noise Lowest Range Noise RMS	Drift and Noise Lowest Range (typical) 2σ
DUAL DIODE SENSORS								
51011 (EMC) 50Ω N(M)	10 kHz to 8 GHz	Note 6a -60 to +10 dBm -60 to +20 dBm -60 to +20 dBm	1 W for 1 µS 300 mW	10 kHz to 2 GHz 2 GHz to 4 GHz 4 GHz to 8 GHz	1.12 1.20 1.40	150 pW	65 pW	130 pW
51011 (4B) 50Ω N(M)	100 kHz to 12.4 GHz	Note 6a -60 to +10 dBm -60 to +20 dBm -60 to +20 dBm	1 W for 1 µS 300 mW	100 kHz to 2 GHz 2 GHz to 4 GHz 4 GHz to 11 GHz 11 GHz to 12.4 GHz	1.12 1.20 1.40 1.60	150 pW	65 pW	130 pW
51012 (4C) 75Ω N(M)	100 kHz to 1 GHz	Note 6a -60 to +10 dBm -60 to +20 dBm -60 to +20 dBm	1 W for 1 µS 300 mW	100 kHz to 1 GHz	1.18	150 pW	65 pW	130 pW
51012 (4C) - S/4 75Ω N(M)	100 kHz to 2 GHz	Note 6a -60 to +10 dBm -60 to +20 dBm -60 to +20 dBm	1 W for 1 µS 300 mW	100 kHz to 2 GHz	1.18	150 pW	65 pW	130 pW
51013 (4E) 50Ω N(M)	100 kHz to 18 GHz	Note 6a -60 to +10 dBm -60 to +20 dBm -60 to +20 dBm	1 W for 1 µS 300 mW	100 kHz to 4 GHz 4 GHz to 10 GHz 10 GHz to 18 GHz	1.30 1.50 1.70	150 pW	65 pW	130 pW
51075 50Ω N(M)	500 kHz to 18 GHz	Note 6a -60 to +10 dBm -70 to +20 dBm -70 to +20 dBm	1 W for 1 µS 300 mW	500 kHz to 2 GHz 2 GHz to 6 GHz 6 GHz to 18 GHz	1.15 1.20 1.40	100 pW	30 pW	60 pW

Refer to NOTES on Page 7.

Table 2-1. Diode and Thermocouple Sensor Characteristics Cont.

Model (Impedance) (RF Connector)	Freq. Range	Dynamic Range 4200A 4220A 4300 Note 7	Overload Rating Peak Power CW Power	Maximum SWR		Drift and Noise Lowest Range		
				Frequency	SWR	Drift (typical) 1 HR (Note 4)	Noise RMS	(typical) 2σ
DUAL DIODE SENSORS CONT.								
51015 (5E) 50Ω N(M)	100 kHz to 18 GHz	Note 6a -50 to +20 dBm -50 to +30 dBm -50 to +30 dBm	10 W for 1 μS 2 W	100 kHz to 1 GHz 1 GHz to 2 GHz 2 GHz to 4 GHz 4 GHz to 12 4 GHz 12.4 GHz to 18 GHz	1.07 1.10 1.12 1.18 1.28	1.5 nW	.65 nW	1.3 nW
51033 (6E) 50Ω N(M)	100 kHz to 18 GHz	Note 6a -40 to +30 dBm -40 to +33 dBm -40 to +33 dBm	100 W for 1 μS 2 W	100 kHz to 1 GHz 1 GHz to 2 GHz 2 GHz to 4 GHz 4 GHz to 12 4 GHz 12 4 GHz to 18 GHz	1.07 1.10 1 12 1 18 1.28	15 nW	6.5 nW	13 nW
51071 50Ω K(M)	10 MHz to 26.5 GHz	Note 6b -60 to +10 dBm -70 to +20 dBm -70 to +20 dBm	1 W for 1 μS 300 mW	10 MHz to 2 GHz 2 GHz to 4 GHz 4 GHz to 18 GHz 18 GHz to 26 5 GHz	1 15 1.20 1.45 1.50	100 pW	30 pW	60 pW
51072 50Ω K(M)	30 MHz to 40 GHz	Note 6b -60 to +10 dBm -70 to +20 dBm -70 to +20 dBm	1 W for 1 μS 300 mW	30 MHz to 4 GHz 4 GHz to 38 GHz 38 GHz to 40 GHz	1 25 1 65 2 00	100 pW	30 pW	60 pW
51078 50Ω N(M)	100 kHz to 18 GHz	Note 6b Note 1 -20 to +37 dBm -20 to +37 dBm	100 W for 1 μS 7W	100 kHz to 4 GHz 4 GHz to 12 GHz 12 GHz to 18 GHz	1 15 1.25 1 40	150 nW	65 nW	130 nW
THERMOCOUPLE SENSORS								
51100 (9E) 50Ω N(M)	10 MHz to 18 GHz	Note 6c -20 to +20 dBm -20 to +20 dBm -20 to +20 dBm	15W 300 mW Note 2	10 MHz to 30 MHz 30 MHz to 16 GHz 16 GHz to 18 GHz	1.25 1 18 1.28	200 nW	100nW	200nW
51101 50Ω N(M)	100 kHz to 4.2 GHz	Note 6c -20 to +20 dBm -20 to +20 dBm -20 to +20 dBm	15W 300 mW Note 2	100 kHz to 300 kHz 100 kHz to 2 GHz 2 GHz to 4.2 GHz	1 70 1.35 1 60	200 nW	100 nW	200 nW
51102 50Ω K(M)	30 MHz to 26.5 GHz	Note 6c -20 to +20 dBm -20 to +20 dBm -20 to +20 dBm	15 W 300 mW Note 2	30 MHz to 2 GHz 2 GHz to 18 GHz 18 GHz to 26.5 GHz	1 35 1.40 1.60	200 nW	100 nW	200 nW
51200 50Ω N(M)	10 MHz to 18 GHz	Note 6c Note 1 0 to +37 dBm 0 to +37 dBm	150 W 10 W Note 3	10 MHz to 2 GHz 2 GHz to 12.4 GHz 12 4 GHz to 18 GHz	1 10 1.18 1.28	20 μW	10 μW	20 μW
51201 50Ω N(M)	100 kHz to 4.2 GHz	Note 6c Note 1 0 to +37 dBm 0 to +37 dBm	150 W 10 W Note 3	100 kHz to 2 GHz 2 GHz to 4.2 GHz	1.10 1.18	20 μW	10 μW	20 μW
51300 50 Ω N(M)	10 MHz to 18 GHz	Note 6c Note 1 0 to +44 dBm 0 to +44 dBm	150 W 50 W Note 3	10 MHz to 2 GHz 2 GHz to 12.4 GHz 12.4 GHz to 18 GHz	1.10 1.18 1.28	50 μW	25 μW	50 μW
51301 50Ω N(M)	100 kHz to 4.2 GHz	Note 6c Note 1 0 to +44 dBm 0 to +44 dBm	150 W 50 W Note 3	100 kHz to 2 GHz 2 GHz to 4.2 GHz	1.10 1.18	50 μW	25 μW	50 μW

Refer to NOTES on Page 7.

Table 2-1. Diode and Thermocouple Sensor Characteristics Cont.

NOTES

1. Not compatible.

2. Thermocouple Pulse Characteristics at 25°C: Maximum pulse energy = 30 w-µsec. (per pulse).

3. Thermocouple Pulse Characteristics at 25°C: Maximum pulse energy = 300 w-µsec. (per pulse).

4. After two-hour warm-up: High frequency power linearity uncertainty: (worst case) 4B, 4C, 4E (0.005 x f) dB per dB above +4 dBm; (above +14 dBm for the 5E and above +24 dBm for the 6E), where f is in GHz.

5. Power linearity Uncertainty at 50 MHz:
   <10 dBm: 1% for 4B, 4C, 4E, 5E, 6E, 9E, 51071, 51072 and 51075 sensors.
   10 to 20 dBm: 1% for 5E and 6E sensors; 3% for 4B, 4C and 4E sensors.
   20 to 33 dBm: 3% for 5E and 6E sensors.
   10 to 17 dBm: 3% for 51071, 51072 and 51075 sensors.
   17 to 20 dBm: 6% for 51071, 51072 and 51075 sensors.
   30 to 37 dBm: 3% for 51078 sensor.

6. Temperature Influence
   a) 0 to 25°C: 0.02 dB/°C; 25 to 55°C: 0.01 dB/°C
   b) 0 to 55°C: 0.03 dB/°C
   c) 0 to 55°C: 0.01 dB/°C

7. Applies to Model 4200 and Model 4220.

Table 2-2. Waveguide Sensor Characteristics

Model (Impedance) (RF Connector)	Frequency Range	PWR Range (Note 1) (Watts) (dBm)	Overload Rating (Watts) (dBm)	Maximum SWR		Drift & Noise Lowest Range		
				Frequency	SWR	Drift (typical) 1 HR (Note 2)	Noise RMS	(typical) 2σ
WAVEGUIDE SENSOR CHARACTERISTICS								
51035 (4K) WR-42 UG-595/U	18 GHz to 26.5 GHz	10 nW to 10 mW -50 to +10 dBm Note 1 -40 to +10 dBm	100 mW +20 dBm	18 GHz to 26.5 GHz	1.45	200 pW	60 pW	120 pW
51036 (4KA) WR-28 UG-599/U	26.5 GHz to 40 GHz	10 nW to 10 mW -50 to +10 dBm Note 1-40 to +10 dBm	100 mW +20 dBm	26.5 GHz to 40 GHz	1.45	60 pW	15 pW	30 pW
51037 (4Q) WR-22 UG-383/U	33 GHz to 50 GHz	10 nW to 10 mW -50 to +10 dBm	100 mW +20 dBm	33 GHz to 50 GHz	1.45	60 pW	15 pW	30 pW
51045 (4U) WR-19 UG-383/U	40 GHz to 60 GHz	10 nW to 10 mW -50 to +10 dBm	100 mW +20 dBm	40 GHz to 60 GHz	1 45	60 pW	15 pW	30 pW
51046 (4V) WR-15 UG-385/U	50 GHz to 75 GHz	10 nW to 10 mW -50 to +10 dBm	100 mW +20 dBm	50 GHz to 75 GHz	1.45	60 pW	15 pW	30 pW
51047 (4W) WR-10 UG-387/U	75 GHz to 100 GHz	32 nW to 10 mW -45 to +10 dBm	100 mW +20 dBm	75 GHz to 100 GHz	1.45	60 pW	15 pW	30 pW

NOTES

1. If used with Model 4200A RF Power Meter.

2. After two-hour warm up: Power Linearity Uncertainty at Reference Frequency: <10 dBm: 0.5 dB all Waveguide Sensors.

Table 2-3. Peak Power Sensor Characteristics

Model Impedance RF Connector	Frequency Range	Power Measurement Peak Power Range CW Power Range Internal Trigger Range	Overload Rating Peak Power CW Power	Rise Time High Bandwidth	Rise Time Low Bandwidth	Maximum SWR Frequency	Maximum SWR Reflection Coefficient	Drift & Noise Peak Power CW Power
PEAK POWER SENSORS								
56218 50Ω N(M)	0.03 to 18 GHz	-24 to +20 dBm -34 to +20 dBm -10 to +20 dBm	1W for 1µS 200 mW	<150 ns (3 MHz)	<500 ns (700 kHz)	below 1GHz 1 to 6 GHz 6 to 18 GHz	1.15 (0.070) 1.20 (0.091) 1.25 (0.111)	4 µW 0.4 µW
56318 50Ω (N(M)	0.5 to 18 GHz	-24 to +20 dBm -34 to +20 dBm -10 to +20 dBm	1 W for 1 µS 200 mW	<15 ns (35 MHz)	<200 ns (1.75 MHz)	below 1 GHz 1 to 6 GHz 6 to 16 GHz 16 to 18 GHz	1.15 (0.070) 1.20 (0.091) 1.28 (0.123) 1.34 (0.145)	4 µW 0.4 µW
56326 50Ω K(M)	0.5 to 26.5 GHz	-24 to +20 dBm -34 to +20 dBm -10 to +20 dBm	1 W for 1 µS 200 mW	<15 ns (35 MHz)	<200 ns (1.75 MHz)	below 1 GHz 1 to 4 GHz 4 to 18 GHz 18 to 26.5 GHz	1.15 (0.070) 1.20 (0.091) 1.45 (0.184) 1.50 (0.200)	4 µW 0.4 µW
56340 50Ω K(M)	0.5 to 40 GHz	-24 to +20 dBm -34 to +20 dBm -10 to +20 dBm	1 W for 1 1S 200 mW	<15 ns (35 MHz)	<200 ns (1.75 MHz)	below 1 GHz 1 to 4 GHz 4 to 38 GHz 38 to 40 GHz	1.25 (0.111) 1.25 (0.111) 1.65 (0.245) 2.00 (0.333)	4 µW 0.4 µW
56418 50 Ω N(M)	0.5 to 18 GHz	-34 to +5 dBm -40 to +5 dBm -18 to +5 dBm	1 W for 1 µS 200 mW	<30 ns (15 MHz)	<100 ns (6 MHz)	below 1 GHz 1 to 6 GHz 6 to 16 GHz 16 to 18 GHz	1.15 (0.070) 1.20 (0.091) 1.28 (0.123) 1.34 (0.145)	400 nW 100 nW
56518 50Ω N(M)	0.5 to 18 GHz	-40 to +20 dBm -50 to +20 dBm -27 to +20 dBm	1W for 1 µS 200 mW	<100 ns (6 MHz)	<300 ns (1.16 MHz)	below 1 GHz 1 to 6 GHz 6 to 16 GHz 16 to 18 GHz	1.15 (0.070) 1.20 (0.091) 1.28 (0.123) 1.34 (0.145)	50 nW 5 nW
56526 50Ω K(M)	0.5 to 26.5 GHz	-40 to +20 dBm -50 to +20 dBm -27 to +20 dBm	1 W for 1 µS 200 mw	<100 ns (6 MHz)	<300 ns (1.16 MHz)	below 1 GHz 1 to 4 GHz 4 to 18 GHz 18 to 26.5 GHz	1.15 (0.070) 1.20 (0.091) 1.45 (0.184) 1.50 (0.200)	50 nW 5 nW
56540 50Ω K(M)	0.5 to 40 GHz	-40 to +20 dBm -50 to +20 dBm -27 to +20 dBm	1 W for 1 µS 200 mW	<100 ns (6 MHz)	<300 ns (1.16 MHz)	below 1 GHz 1 to 4 GHz 4 to 38 GHz 38 to 40 GHz	1.25 (0.111) 1.25 (0.111) 1.65 (0.245) 2.00 (0333)	50 nW 5 nW

NOTES

1. The above sensors are for use with the Model 4400 Peak Power Meter and the Model 4500 Digital Sampling Power Analyzer. The frequency correction calibration factors are stored within the sensor and the linearity calibration is performed by the built-in calibrator.

2. All sensors feature a balanced dual diode configuration for high sensitivity and even-order harmonic suppression.

3. Low VSWR minimizes possible mismatch errors. Calibration factors are NIST traceable.

4. Temperature Influence - No additional uncertainty within ± 4°C after autocalibration.

Power Sensor Uncertainty Factors

The uncertainty factors, as a function of frequency for the Diode & Thermocouple and Waveguide Sensors, are listed in Tables 3-1 and 3-2 respectively.

Table 3-1. Diode & Thermocouple Power Sensor Calibration Factor Uncertainty
Models 51011(4B), 51011(EMC), 51012(4C), 51012(4C-S/4), 51013(4E), 51015(5E), 51033(6E), 51100(9E)

f GHz	MODEL									
	51011(4B) 51011(EMC)		51012(4C) 51012(4C-S/4)		51013(4E)		51015(5E) 51033(6E)		51100(9E)	
	Max: %	RSS: %	Max: %	RSS: %	Max: %	RSS: %	Max: %	RSS: %	Max: %	RSS: %
DIODE AND THERMOCOUPLE SENSORS										
0.03	1.14	0.87	4.30	3.10	1.14	0.87	1.22	0.88	2.01	1.29
0.30	1.72	1.55	3.94	2.78	1.72	1.55	1.80	1.56	2.35	1.71
0.50	1.88	1.44	3.91	2.78	2.52	1.76	1.68	1.38	2.10	1.53
1	1.93	1.45	3.90	2.80	2.57	1.77	1.86	1.42	2.16	1.54
2	2.61	1.95	4.49	3.33	2.95	2.11	2.23	1.83	2.53	1.92
3	2.50	1.68			2.84	1.87	2.21	1.57	2.43	1.65
4	3.07	2.06			2.76	1.86	2.13	1.56	2.35	1.64
5	3.09	2.04			3.37	2.25	2.36	1.62	2.36	1.62
6	3.31	2.24			3.60	2.43	2.59	1.86	2.59	1.86
7	3.07	2.03			3.35	2.24	2.34	1.60	2.34	1.60
8	3.29	2.28			3.58	2.47	2.57	1.91	2.57	1.91
9	5.10	3.42			5.70	3.96	3.57	2.18	3.57	2.18
10	5.33	3.46			5.93	4.00	3.80	2.25	3.80	2.25
11	4.71	3.35			6.40	4.93	3.18	2.08	3.18	2.08
12	6.16	4.47			6.68	4.96	3.46	2.14	3.46	2.14
13					7.50	5.14	5.01	3.02	4.28	2.53
14					7.14	5.03	4.65	2.84	3.92	2.31
15					6.36	4.95	3.87	2.67	3.14	2.10
16					6.81	5.07	4.32	2.89	3.59	2.37
17					6.85	5.01	4.36	2.80	4.36	2.80
18					7.59	5.15	5.10	3.04	5.10	3.04

Table 3-1. Diode & Thermocouple Power Sensor Calibration Factor Uncertainty (Cont.)
Models 51101, 51200, 51300, 51201, 51301, 51075, 51078

f GHz	MODEL									
	51101		51200 51300		51201 51301		51075		51078	
	Max: %	RSS: %	Max: %	RSS; %	Max: %	RSS %	Max: %	RSS: %	Max: %	RSS: %
DIODE AND THERMOCOUPLE SENSORS										
0.03	2.34	1.63	1.46	0.96	2.34	1.63	1.22	0.88	1.22	0.88
0.30	2.33	1.62	2.05	1.61	2.33	1.62	1.80	1.56	1.80	1.56
0.50	2.33	1.62	1.80	1.41	2.33	1.62	1.99	1.48	1.99	1.48
1	2.41	1.65	1.86	1.42	2.41	1.65	2.05	1.49	2.05	1.49
2	3.26	2.28	2.53	1.92	3.26	2.28	2.61	1.95	2.61	1.95
3	3.43	2.32	2.43	1.65	3.43	2.32	2.50	1.68	2.50	1.68
4	3.55	2.40	2.35	1.64	3.55	2.40	2.42	1.67	2.59	1.76
5			2.36	1.62			2.43	1.65	2.61	1.74
6			2.59	1.86			3.32	2.24	2.83	1.97
7			2.34	1.91			3.07	2.03	2.59	1.72
8			2.57	1.91			3.29	2.28	2.81	2.01
9			3.57	2.18			5.10	3.42	4.08	2.56
10			3.80	2.25			5.33	3.47	4.31	2.62
11			3.18	2.08			4.71	3.36	3.70	2.48
12			3.46	2.14			5.00	3.40	5.00	3.40
13			5.01	3.02			5.82	3.65	5.82	3.65
14			4.65	2.84			5.45	3.50	5.45	3.50
15			3.87	2.67			4.68	3.37	4.68	3.37
16			4.32	2.89			5.12	3.55	5.12	3.55
17			4.36	2.80			5.17	3.47	5.17	3.47
18			5.10	3.04			5.91	3.67	5.91	3.67

Table 3-1. Diode & Thermocouple Power Sensor Calibration Factor Uncertainty (Cont.)
Models 51102, 511071, 51072

f GHz	MODEL					
	51102		51071		51072	
	Max: %	RSS: %	Max: %	RSS; %	Max: %	RSS: %
DIODE AND THERMOCOUPLE SENSORS						
0.03	1.83	1.19	1.40	0.95	1.62	1.06
0.50	2.34	1.64	1.83	1.41	2.10	1.51
1	2.29	1.63	1.79	1.39	2.05	1.50
2	2.58	1.82	2.02	1.50	2.17	1.57
3	2.62	1.85	2.07	1.54	2.21	1.61
4	2.79	1.97	2.91	2.05	3.36	2.37
5	3.08	2.14	3.22	2.23	3.74	2.61
6	3.31	2.28	3.45	2.36	3.96	2.72
7	3.57	2.42	3.72	2.52	4.28	2.92
8	3.81	2.61	3.96	2 70	4.53	3.08
9	3.69	2.55	3.84	2.65	4.40	3.04
10	3.54	2.50	3.69	2.59	4.25	2.98
11	3.80	2.65	3.95	2.74	4.51	3.11
12	3.76	2.58	3.91	2.67	4.47	3.05
13	4.00	2.74	4.17	2.85	4.79	3.29
14	4.07	2.84	4.26	2.97	4.94	3.47
15	4.38	3.03	4.55	3.13	5.17	3.53
16	4.71	3.21	4.87	3.30	5.49	3.68
17	5.01	3.45	5.17	3.54	5.79	3.89
18	5.42	3.79	5.14	3.64	5.55	3.86
19	5.51	3.90	5.23	3.76	5.64	3.97
20	6.45	4.48	6.18	4.35	6.58	4.54
21	7.00	4.94	6.75	4.85	7.12	4.98
22	6.93	4.64	6.65	4.53	7.06	4.70
23	6.84	4.80	6.59	4.71	6.95	4.85
24	5.90	4.09	5.65	3.98	6.01	4.14
25	5.94	4.23	5.72	4.15	6.04	4.27
26	6.19	4.28	5.97	4.20	6.28	4.31
27					7.73	5.86
28					5.86	4.17
29					6.33	4.73
30					6.87	5.16
31					8.63	6.43
32					10.22	7.34
33					10.00	7.03
34					8.40	5.75
35					7.09	4.86
36					8.10	5.46
37					8.32	5.43
38					9.13	6.09
39					8.55	6.02
40					10.78	7.14

Table 3-2. Peak Power Sensor Calibration Factor Uncertainty

f GHz	MODEL							
	56218		56318 56418 56518		56326 56526		56340 56540	
	Max: %	RSS: %	Max: %	RSS; %	Max: %	RSS: %	Max: %	RSS: %
PEAK POWER SENSORS								
0.03	1.65	1.06						
0.30	2.24	1.67						
0.50	1.99	1.48	1.99	1.48	1.83	1.41	2.10	1.51
1	2.23	1.57	2.23	1.57	1.79	1.39	2.05	1.50
2	2.61	1.95	2.61	1.95	2.02	1.50	2.17	1.57
3	2.50	1.68	2.50	1.68	2.07	1.54	2.21	1.61
4	2.42	1.67	2.42	1.67	2.91	2.05	3.36	2.37
5	2.43	1.65	2.43	1.65	3.22	2.23	3.74	2.61
6	2.83	1.97	2.94	2.02	3.45	2.36	3.96	2.72
7	2.59	1.72	2.69	1.78	3.72	2.52	4.28	2.92
8	2.81	2.01	2.91	2.06	3.96	2.70	4.53	3.08
9	4.08	2.56	4.30	2.74	3.84	2.65	4.40	3.04
10	4.31	2.62	4.53	2.79	3.69	2.59	4.25	2.98
11	3.70	2.48	3.91	2.66	3.95	2.74	4.51	3.11
12	3.98	2.53	4.20	2.71	3.91	2.67	4.47	3.05
13	4.80	2.86	5.02	3.02	4.17	2.85	4.79	3.29
14	4.44	2.67	4.65	2.84	4.26	2.97	4.94	3.47
15	3.66	2.50	3.88	2.68	4.55	3.13	5.17	3.53
16	4.11	2.73	4.72	3.21	4.87	3.30	5.49	3.68
17	4.15	2.63	4.77	3.13	5.17	3.54	5.79	3.89
18	4.89	2.88	5.51	3.34	5.14	3.64	5.55	3.86
19					5.23	3.76	5.64	3.97
20					6.18	4.35	6.58	4.54
21					6.75	4.85	7.12	4.98
22					6.65	4.53	7.06	4.70
23					6.59	4.71	6.95	4.85
24					5.65	3.98	6.01	4.14
25					5.72	4.15	6.04	4.27
26					5.97	4.20	6.28	4.31
27							7.73	5.86
28							5.86	4.17
29							6.33	4.73
30							6.87	5.16
31							8.63	6.43
32							10.22	7.34
33							10.00	7.03
34							8.40	5.75
35							7.09	4.86
36							8.10	5.46
37							8.32	5.43
38							9.13	6.09
39							8.55	6.02
40							10.78	7.14

Table 3-3. Waveguide Sensor Calibration Uncertainty Factors

Model	Reference Frequency (GHz)	At Reference Frequency		Over Sensor Bandwidth	
		(%)	(AVG dB)	(%)	(AVG dB)
WAVEGUIDE SENSORS					
51035(4K)	22	6	0.27	6	0.27
51036 (4KA)	33	6	0.27	10	0.46
51037 (4Q)	40	10	0.46	13	0.60
51045 (4U)	50	10	0.46	13	0.60
51046 (4V)	60	12	0.56	13	0.60
51047 (4W)	94	13	0.60	13	0.60

NOTE

For Waveguide Sensors, the reference calibration is at -10 dBm. For levels other than -10 dBm there is an additional uncertainty of 0.01 dB per dB relative to -10 dBm.

4

Low Frequency Response and Standing-Wave-Ratio (SWR) Data

The typical performance data that follows is not guaranteed, however, it represents a large number of production units processed. Therefore, it is a good guideline for user expectations. The worst case specifications are quite conservative in accordance with BEC's general policy.

Detailed SWR data is supplied with each sensor unit shipped against a customer order to give the user specific information required to properly evaluate errors in a particular application. Please consult the factory for optional units with more stringent specifications.

The typical low frequency response for three sensor models are shown in Figures 4-1 through 4-3. Figures 4-4 through 4-10 represent SWR Data.

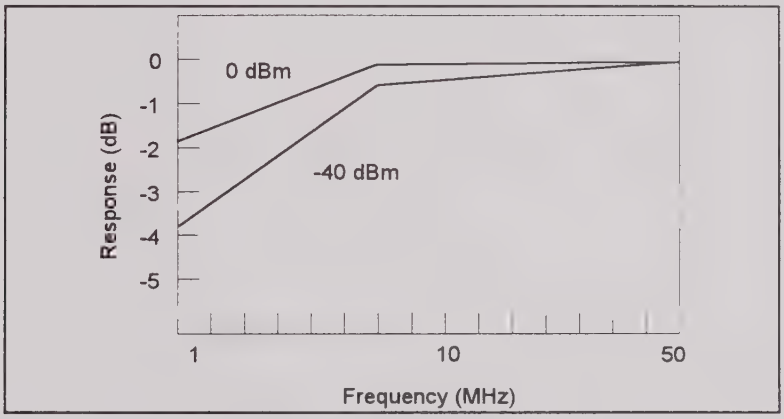


Figure 4-1. Model 51071 Low Frequency Response

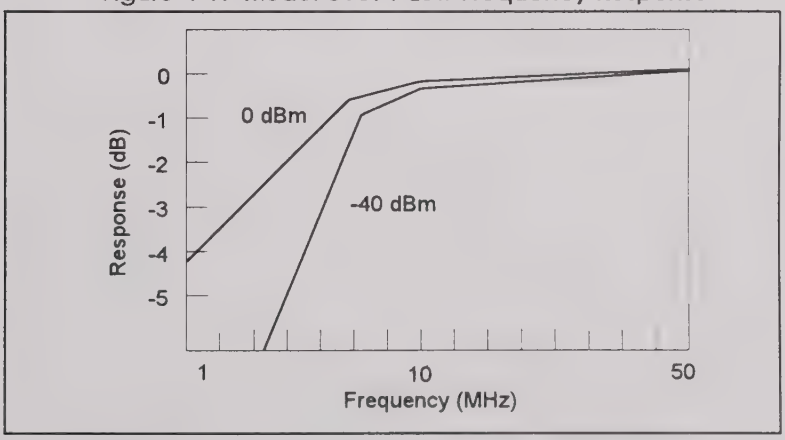


Figure 4-2. Model 51072 Low Frequency Response

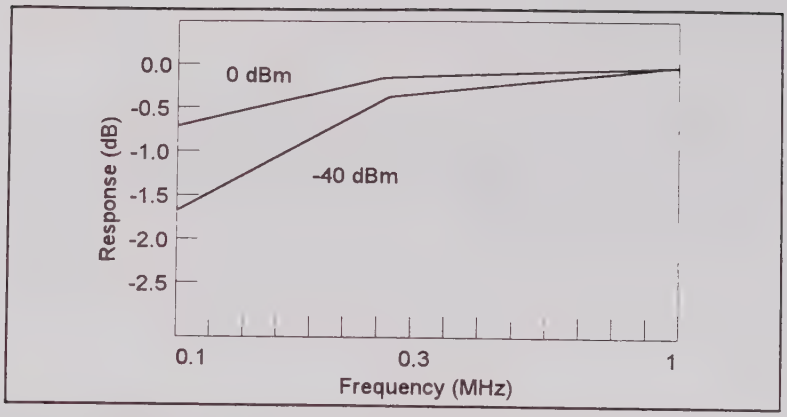


Figure 4-3. Model 51075 Low Frequency Response

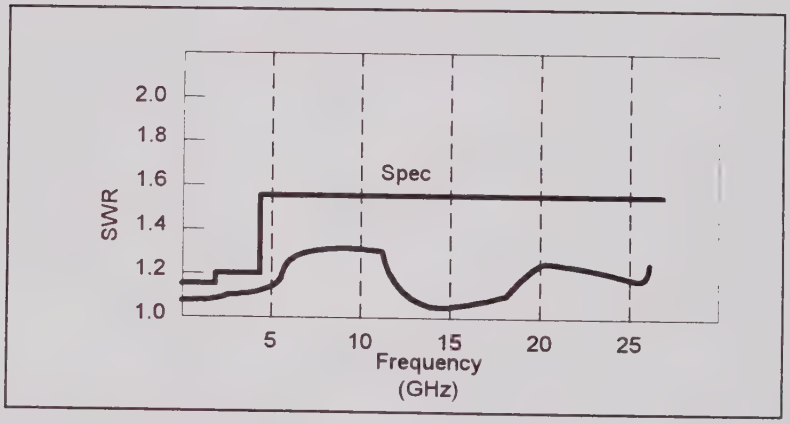


Figure 4-4. Model 51071 SWR Data

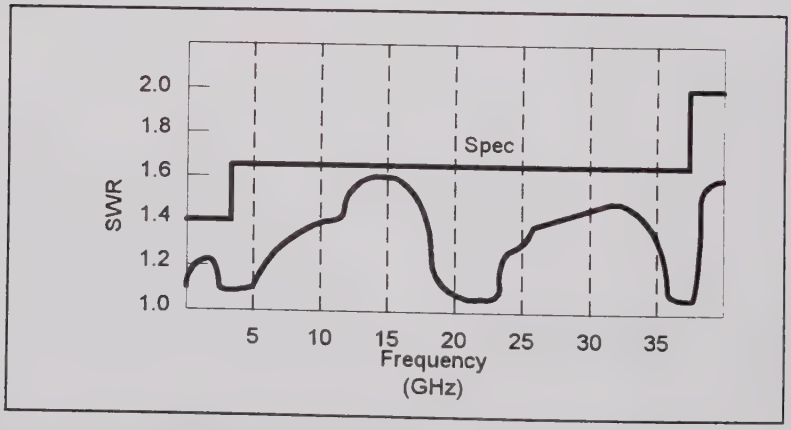


Figure 4-5. Model 51072 SWR Data

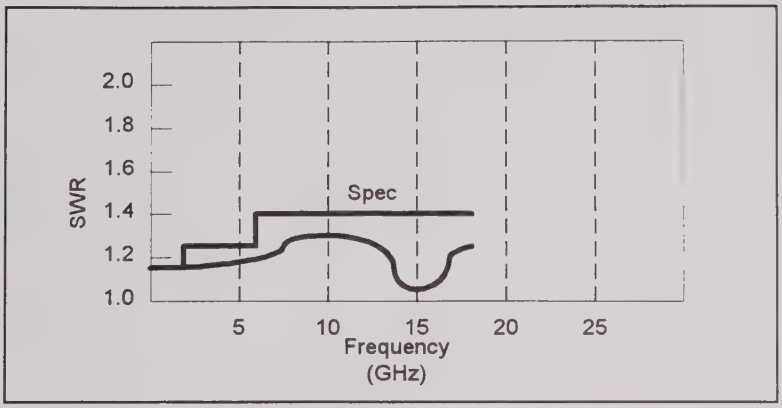


Figure 4-6. Model 51075 SWR Data

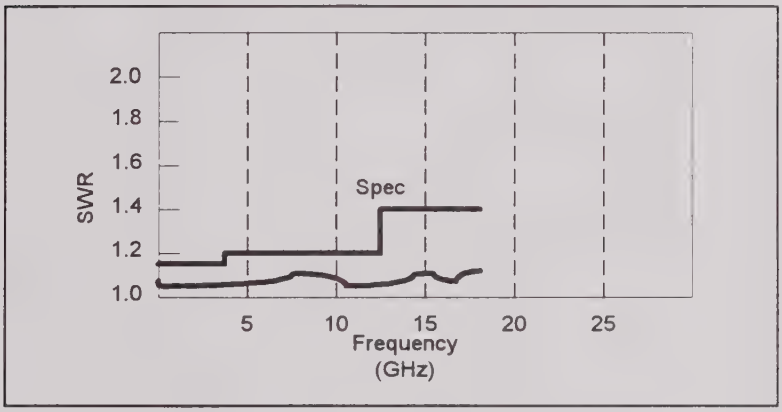


Figure 4-7. Model 51078 SWR Data

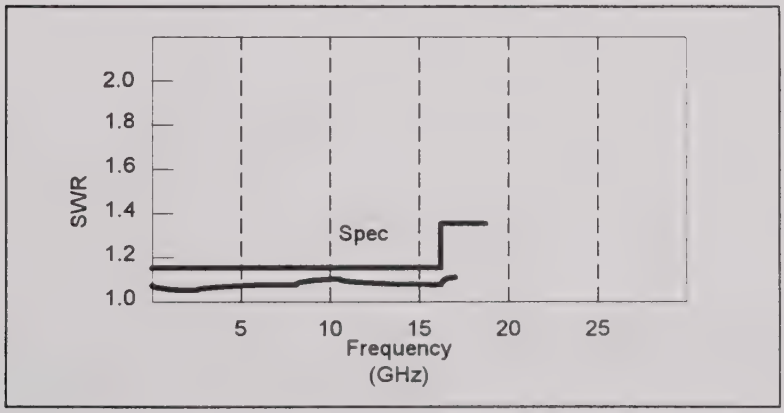


Figure 4-8. Model 51100 SWR Data

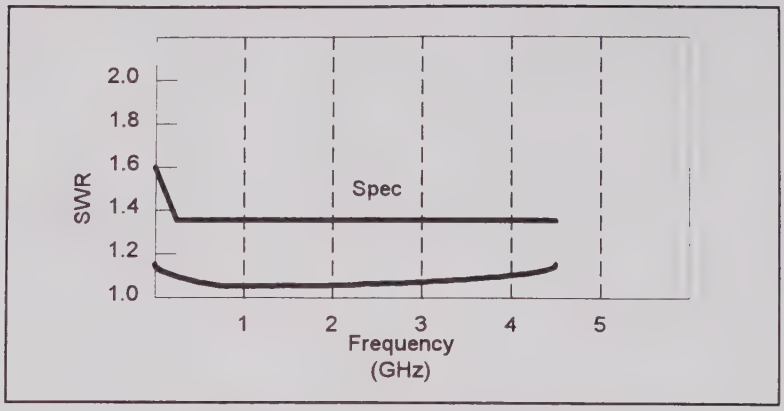


Figure 4-9. Model 51101 SWR Data

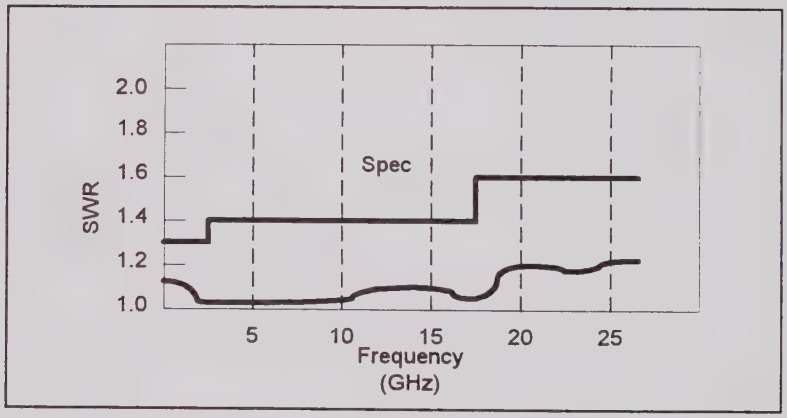


Figure 4-10. Model 51102 SWR Data

Pulsed RF Power

5-1 Pulsed RF Power Operation

Although this manual discusses power sensors used with average responding power meters, for rectangular pulsed RF signals, pulse power can be calculated from average power if the duty cycle of the reoccurring pulse is known. The duty cycle can be found by dividing the pulse width (T) by the period of the repetition frequency or by multiplying the pulse width times the repetition frequency as shown in Figure 5-1.

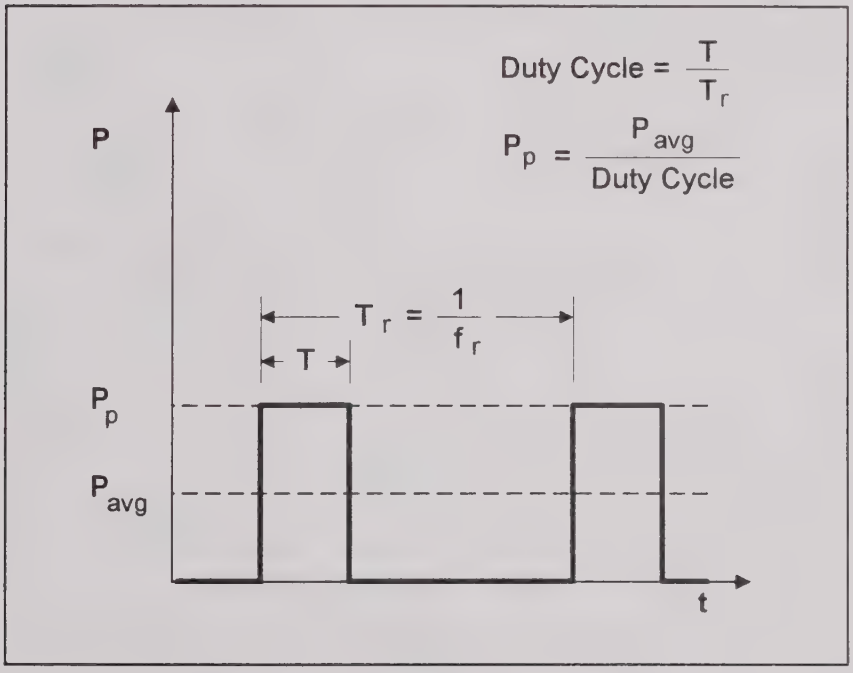


Figure 5-1. Pulsed RF Operation

This technique is valid for the entire dynamic range of Thermocouple Sensors and allows very high pulse powers to be measured. For Diode Sensors, this technique is valid only within the square-law region of the diodes.

5-2 Pulsed RF Operation Thermocouple Sensors

Figure 5-2 shows the regions of valid duty cycle and pulse power that apply to the Thermal Sensors. As the duty cycle decreases, the average power decreases for a given pulse power and the noise becomes a limitation. Also, there is a pulse power overload limitation. No matter how short the duty cycle is, this overload limitation applies. Lastly, the average power cannot be exceeded (there is some headroom between the measurement limitation and the burnout level of the sensor).

Since the detection process in Thermal Sensors is heat, Thermal Sensors can handle pulse powers that are two orders of a magnitude larger than their maximum average power. This makes them ideal for this application. The minimum pulse repetition frequency for the Thermal Sensors is approximately 100 Hz.

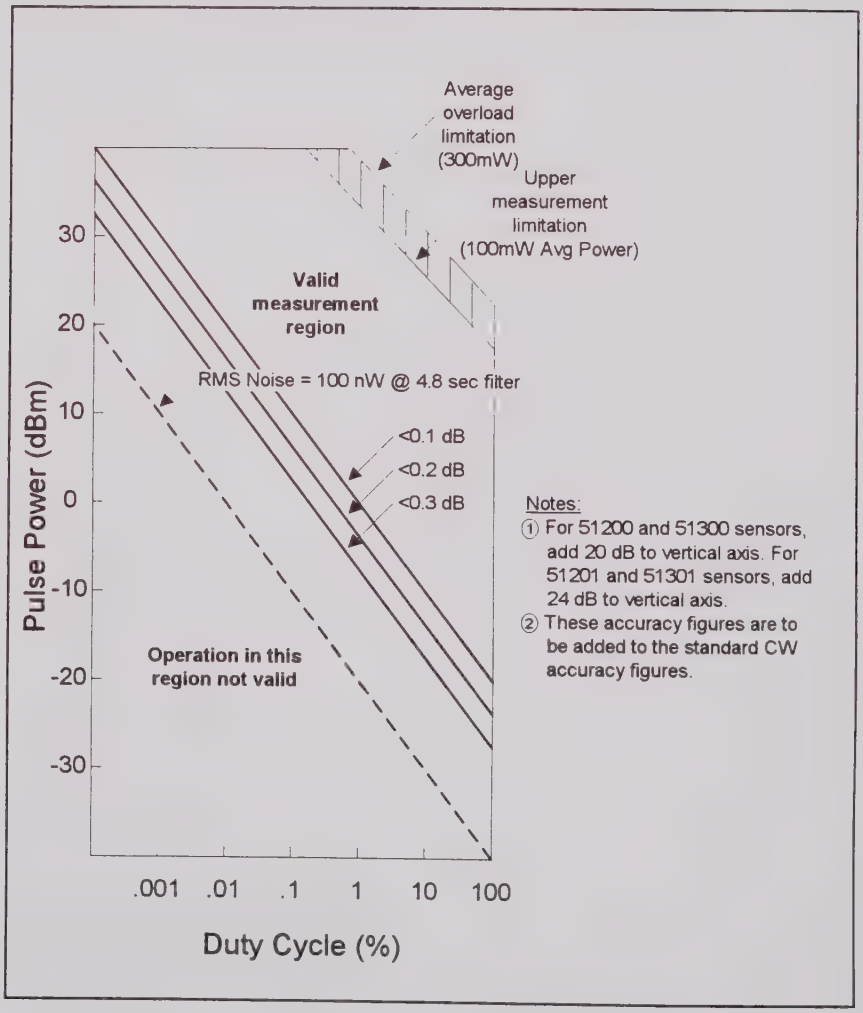


Figure 5-2. Pulsed Accuracy for Thermocouple Sensors

5-3 Pulsed RF Operation Diode Sensors

Figure 5-3 shows the valid operating region for the Diode Sensors. As with Thermal Sensors, the bottom end measurement is limited by noise, getting worse as the duty cycle decreases. At the top end, the limitation is on pulse power because even a very short pulse will charge up the detecting capacitors. The burnout level for Diode Sensors is the same for the pulsed and CW waveforms. The minimum pulse repetition frequency is 10 kHz.

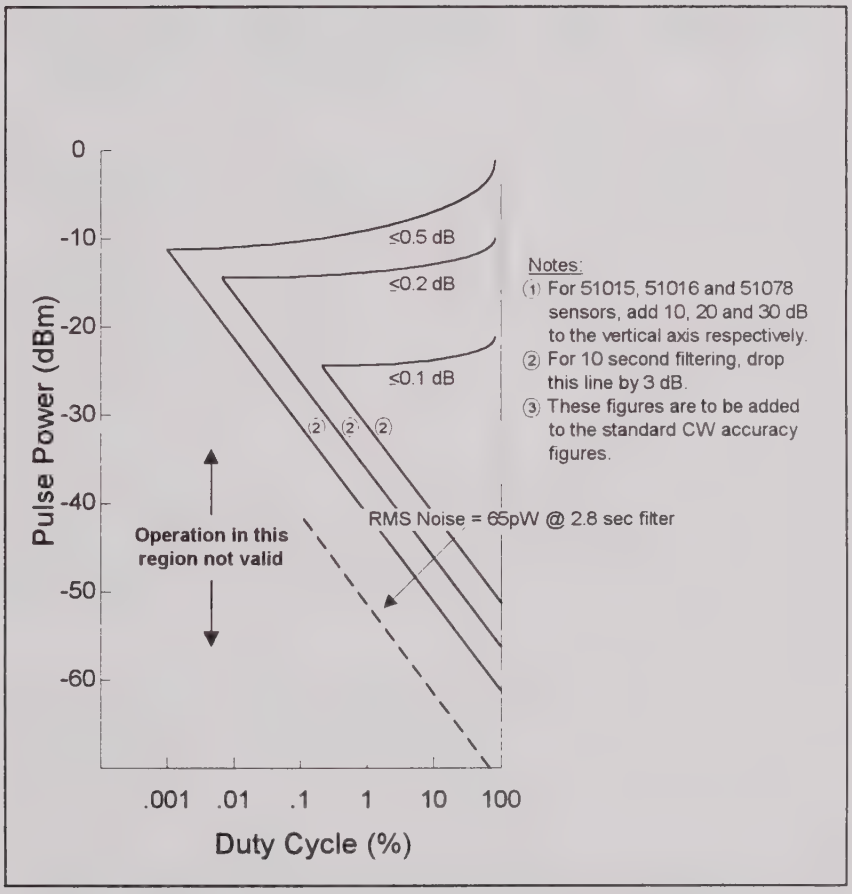

0
-10
-20
-30
-40
-50
-60
Pulse Power (dBm)
≤0.5 dB
≤0.2 dB
≤0.1 dB
Notes:
(1) For 51015, 51016 and 51078 sensors, add 10, 20 and 30 dB to the vertical axis respectively.
(2) For 10 second filtering, drop this line by 3 dB.
(3) These figures are to be added to the standard CW accuracy figures.
(2) (2) (2)
RMS Noise = 65pW @ 2.8 sec filter
Operation in this region not valid
.001 .01 .1 1 10 100
Duty Cycle (%)

Figure 5-3. Pulsed Accuracy for Diode Sensors

6

Calculating Measurement Uncertainty

6-1 Theory

Calculating measurement uncertainty can be a confusing issue. Once the power meter has been set up with its sensor, the measurement errors fall into three categories. These categories are **Power Dependent Errors, Frequency Dependent Errors,** and finally **Power and Frequency Independent Errors.**

Power Dependent Errors consist of zeroing error, noise error and linearity error. Zeroing error refers to the residual offset due to noise present during an auto zero operation. This becomes more critical at lower power levels. Another error that becomes a concern at lower power levels is the noise error. This error can be reduced by the use of extended averaging, however, this will increase measurement time. The final error that falls under the category of power dependent is linearity. This is caused due to the nonlinear response of diode and thermocouple sensors at high power levels. BEC sensors reduce this error through the process of linearity calibration, as discussed earlier, however the "shaping" that is performed is not without error and must be added into total uncertainty.

Frequency Dependent Errors are made up of calibration factor uncertainty, mismatch uncertainty, and high frequency linearity error. Calibration factor uncertainty is a function of the accuracy of the equipment used to determine the calibration factor. Mismatch uncertainty arises because usually neither power sensor nor source under test are perfect matches. Mismatch uncertainty can be calculated from the SWR of the sensor and the source under test as shown in Figure 6-1.

For most conditions, the calibration factor uncertainty and mismatch uncertainty will be the largest contributor to total measurement uncertainty. Linearity error was discussed previously as a power dependent error, however, it also becomes a concern at high frequencies. The combination of both high frequency and high power can derate the linearity of the "shaping" process applied to certain types of diode sensors.

Instrumentation errors and power reference error fall under the category of **Power and Frequency Independent Errors**. Circuit limitations and component tolerance within the power meter makes up the instrumentation errors. Power reference error is associated with the internal power reference against which power meter and sensor are routinely calibrated.

Total measurement uncertainty can be expressed as either a worst case uncertainty or RSS uncertainty. The worst case approach is a conservative method where the extreme condition of each individual uncertainty is added to one another. Since each of the individual uncertainties are independent of each other, the probability of all being at the extreme condition is near zero. For this reason, a more realistic method of combining uncertainties was developed, the RSS method. RSS is an abbreviation for "root-sum-of-the-squares". In this method each uncertainty is squared, added to one another, and the square root of the summation is calculated. The formula for RSS is as follows:

$$RSS = \sqrt{(U_1)^2 + (U_2)^2 + (U_3)^2 \ldots \text{etc.}}$$

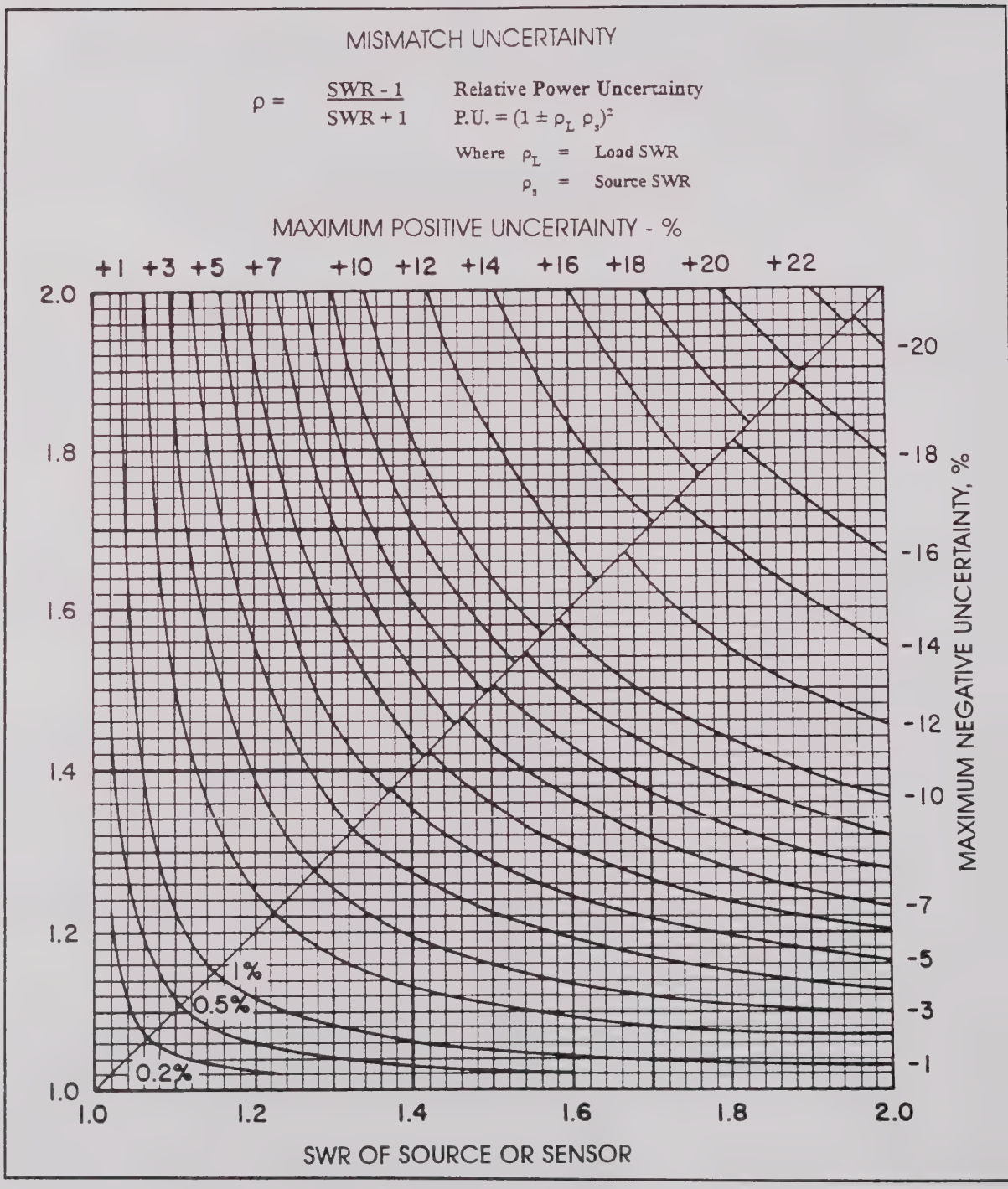


Figure 6-1. Mismatch Uncertainty

6-2 Example

The following example demonstrates how to calculate the total measurement uncertainty of a power measurement. The measurement conditions for this example is as follows:

> The Boonton Model 4220A Power Meter will be used with a Model 51075 Power Sensor to measure a CW signal. The signal will be at a level of -55 dBm and frequency of 7 GHz. The SWR of the source will be 1.50. Finally, we will assume a 5°C temperature change from time of calibration (calibration performed with the 50 MHz, 0 dBm power reference on the 4220A).

Step 1: We must establish the instrumentation uncertainty of the Model 4220A. The specification states 0.23% at full scale or 0.46% at 1/10 of full scale. A level of -55 dBm will be a downscale point for range 0, therefore, the 0.46% specification applies.

Step 2: Since an auto calibration of our sensor was performed, we must add the uncertainty of our power reference. For the 50 MHz, 0 dBm reference, the worst case uncertainty is 1.20%.

Step 3: At a frequency of 7 GHz a calibration factor will be applied to our measurement. The worst case uncertainty of this calibration factor at 7 GHz is 3.1%; (Table 3-1).

Step 4: The next item to calculate is mismatch uncertainty. This uncertainty is calculated from the SWR's of both sensor and source. Once the SWR's are known, we must calculate the reflection coefficient (amplitude only) for both the sensor and source. To find reflection coefficient (ρ), use the formula ρ = SWR - 1 / SWR + 1. After the reflection coefficient is found, mismatch uncertainty is found by using the formula:

$[(1 \pm \rho \text{ sensor} \times \rho \text{ source})^2 - 1] \times 100.$

Example: Source SWR = 1.50, Sensor SWR = 1.40

$$\rho \text{ source} = \frac{1.50 - 1}{1.50 + 1} = 0.2, \quad \rho \text{ sensor} = \frac{1.40 - 1}{1.40 + 1} = 0.167$$

$[(1 \pm 0.2 \times 0.167)^2 - 1] \times 100 = +6.79\%, -6.57\%$

Average Uncertainty will be 6.68% (worst case)

Step 5: The noise specification on the Model 51075 is 30 pW, RMS, therefore, for a signal level of - 55 dBm (3.16 nW), the additional uncertainty due to noise will be 0.95%. This is calculated by using the formula, (signal level/noise specification) x 100.

Step 6: In this step, we will discuss the linearity of the 51075. As shown in Table 2-1 (Notes), this uncertainty will be 1% for levels below 10 dBm.

Step 7: In our example, we mentioned that the temperature of our room has drifted

5°C from the time that we established our 50 MHz, 0 dBm reference. Since all power sensors are temperature sensitive, we must add the sensors drift, due to temperature, into our total uncertainty. If the drift in the 51075 is 0.01 dB per °C, the additional uncertainty in our measurement will be ± 0.05 dB or 1.16%. Please note that performing the auto calibration at the new temperature will cancel out this additional uncertainty.

Step 8: Now that all of the uncertainties have been established, we can combine them to determine the total measurement uncertainty. To find the RSS uncertainty proceed as follows:

Source of Error	Value (%)	Value²(%)
Instrumentation	0.46	0.2116
Power Reference	1.20	1.4400
Calibration Factor	3.10	9.6100
Mismatch	6.68	44.6200
Noise	0.95	0.9025
Linearity (Shaping)	1.00	1.0000
Temperature	1.16	1.3456
Sum of Squares		59.1297
Total RSS Uncertainty		**7.69%**

To find the maximum worst case uncertainty, we would add each of the individual uncertainties (%) as follows:

0.46 + 1.20 + 3.10 + 6.68 + 0.95 +1.00 + 1.16 = 14.55%

6-3 Work Sheet

Source of Error	Value (%)	Value²(%)	Comments
Instrumentation[1]	_____	_____	Includes Zeroing Error
Power Reference[2]	_____	_____	
Calibration Factor[3]	_____	_____	Frequency Dependent
Mismatch[3]	_____	_____	Frequency Dependent (Based on SWR of Sensor & Source)
Noise[4]	_____	_____	Level Dependent - More Critical at Lower Levels
Linearity (Shaping)[5]	_____	_____	Power and Frequency Dependent

Source of Error	Value (%)	(Value)²(%)	Comments
Temperature[6]	_____	_____	
Pulse Accuracy	_____	_____	Only add if measuring pulsed RF Signals (Figures 4 & 5)
	_____		**Total**
		_____	**Sum of Squares**
		_____%	**Total RSS Uncertainty**

[1]Worst case instrumentation accuracy for the BEC RF Power Meters:

Model 4220A	Model 4200A	Model 4300
0.23% at fs 0.46% at 1/10 fs	1.45% rdg + 0.1% fs	0.42% + 0.025% of fs

[2] If 50 MHz, 0 dB power reference is used, uncertainty is 1.20% (worst case); for the 30 MHz programmable calibrator, Model 4321 or Model 4322, the uncertainty is as follows:

Level	Worst Case
@0 dBm	0.9%
+20 to -30 dBm	1.4%
-40 to -60 dBm	2.1%

[3]Mismatch Uncertainty (%) = $[(1 \pm \rho \text{ sensor} \times \rho \text{ source})^2 - 1] \times 100$;

$$\rho = \frac{SWR - 1}{SWR + 1}$$

Refer to Figure 6-1.

[4]Noise Uncertainty (%) = (signal level/noise specification) x 100

[5] If the 30 MHz calibrator (Model 4321 or Model 4322) is used, the linearity uncertainty is included in the instrumentation uncertainty and need not be added again. Add 3% for 5 and 6 series sensors with the 30 MHz calibrator, when above +20 dBm.

[6]Additional uncertainty due to temperature drift can be compensated for through the use of auto calibration.

Warranty

Boonton Electronics Corporation (BEC) warrants its products to the original Purchaser to be free from defects in material and workmanship for a period of one year from date of shipment for instrument, and for one year from date of shipment for probes, power sensors and accessories. BEC further warrants that its instruments will perform within all current specifications under normal use and service for one year from date of shipment. These warranties do not cover active devices that have given normal service, sealed assemblies which have been opened or any item which has been repaired or altered without BEC's authorization.

BEC's warranties are limited to either the repair or replacement, at BEC's option, of any product found to be defective under the terms of these warranties.

There will be no charge for parts and labor during the warranty period. The Purchaser shall prepay shipping charges to BEC or its designated service facility and shall return the product in its original or an equivalent shipping container. BEC or its designated service facility shall pay normal ground shipping charges to return the product to the Purchaser. The Purchaser shall pay all shipping charges, duties and taxes if a product is returned to BEC from outside of the United States.

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